Some of Gott's objections, and ways to take them into account, have been dealt with in the literature. His first objection is that the h-index does not reward an individual for his or her most important paper. Those of us who use the h-index profusely are aware of that concern and simply correct it by looking at the number of citations for the individual's two or three most cited papers.

Gott also objects to the low h-index of scientific giants like Einstein. That also has been discussed in the literature and attributed to the different publication and citation culture—in particular, the low average number of citations per paper—in Einstein's day.[3] A normalization method to correct that problem through time adjustment is presented in reference 3. Once that procedure is applied, Einstein reaches an h-index of 139, higher than any of those mentioned by Gott.

Another objection concerns informal citations—that is, those only mentioning names or initials instead of giving complete references—which Gott calls eponymous or name citations. Again, that has already been discussed at length.[4] The most conspicuous case may be that of C. V. Raman, who has an h-index of 17 with 2500 formal citations; 150 000 informal citations according to INSPEC, the Information Services for the Physics and Engineering Communities database; and 1 million informal citations according to Google Scholar.

Combining formal and informal citations into one index is somewhat misleading because they are based on different metrics with different limitations. For example, abstracts from papers prior to 1991 are not available in the Web of Science. Furthermore, the weighting factors Gott used for calculating his E-index seem to be highly arbitrary, which makes his index opaque, especially when compared with the h-index. Finally, there is extensive literature discussing the relative share of first authors and coauthors in bibliometrical indicators.[5]

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The h-index, impact factors, and similar absurdities are increasingly divorced from the original purpose that spawned them. Citations were intended for forward-referencing, to be able to follow the subsequent development of a topic or field. Just as our publications carry references to past papers to place them in context, citations allow us to see how the work develops into the future.

Originators of science citations may never have meant them to be an evaluation of an author's worth. Yet it seems that awards and promotions are increasingly based on the h-index and other concocted indices. No studies have justified such use, and there is no reason to claim that two people with the same h value are somehow of equal worth. Deans and other administrators, in moments of reflection, will concede that an h-index cannot be used for promotion decisions, but the tempting simplicity of a single number—as with IQ and indicators in the past—is sometimes hard to resist, especially when one is not familiar with the work itself.

The innumeracy is compounded when h is divided by some time unit, such as years ranked as assistant or associate professor or years since PhD. How is that meaningful? We as physicists should know better than to invest meaning simply because we can multiply or divide two numerical quantities. The sole purpose of computing such indices seems to be to make some case for timeliness of promotion. If such a case could be reasonably made, we could do away with any promotion deliberations and just replace them with some automatic gate or threshold.

Even as the amount of literature on- and off-line explodes and purportedly quantitative measures of abilities proliferate, people seem to actually read the literature less and less. Referencing to previous work is often grossly inadequate, especially with authors using electronic search sites and limiting their searches to recent publications. I've also heard of gaming the system, with friends agreeing to cite each other's papers, regardless of relevance, simply to boost their h-index.

In the light of all this, I propose a new index, the r-index. A primary meaning of the "r" is as one of the original three r's, reading. The r-index is the fraction or ratio of the references cited that the author has actually read in full at least once.

My tone should make it clear that I do not want or expect anyone to start computing the r-index, or the h-index, or the latest "E-index" with further rococo embellishments (PHYSICS TODAY, November 2010, page 12). Physicists spawned the h-index. It is for physicists now to banish it from any rational discourse.

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Gott replies: Jorge Hirsch acknowledges his h-index cannot be used to compare people across epochs. That's where I started. Werner Marx and Manuel Cardona think people can be compared across epochs, and they and Lutz Bornmann propose a "renormalized" h-index to do it.[1]

But even comparing contemporaries, Hirsch notes,

> For an author with a relatively low h that has a few seminal papers with extraordinarily high citation counts, the h index will not fully reflect that scientist's accomplishments. Conversely, a scientist with a high h achieved mostly through papers with many coauthors would be treated overly kindly by his or her h.[2]

My E-index addresses those problems by weighting all papers in proportion to their citation impact and dividing credit for each paper among its n authors: counting ½ first-author citations and ½ fractional ($\frac{1}{n}$) citations. Vladimir Krasnopolsky (PHYSICS TODAY, September 2004, page 12) proposed giving ½ citation to the first author of a multiauthor paper with the remaining ½ divided between coauthors—close to what I am doing.

Marx and Cardona actually favor including informal last-name citations, saying,

> The data reveal that the formal citations often measure only a small fraction of the overall impact of seminal publications. Furthermore, informal citations are mainly given instead of (and not in addition to) formal citations. As a major consequence, the overall impact of pioneering articles and researchers cannot be entirely determined by merely counting the full reference based citations.[3]

The E-index includes informal citations by adding last-name citations in titles and abstracts to the average of first-author and fractional citations. That recovers additional "lost" citations that Albert Einstein and other greats are getting, mostly from recent times, and allows comparison with recent physicists

without requiring renormalization.

The e-index that Cardona and Marx mention is for excess citations[4] and is not to be confused with my E-index. It recognizes the seminal-paper problem by counting all citations in the author's most cited h papers to come closer to the total citation count.

The E-index is proportional to impact and can be measured in milli-Einsteins (mE). C. V. Raman is high, but when people mention Raman spectroscopy in titles or abstracts, it's hard to argue they aren't referring to his Nobel Prize–winning work. The 20th- and 21st-century physicists and astronomers I've found with the top E-index values are Raman (1468 mE), Enrico Fermi (1277), Einstein (1000), and Edwin Hubble (815), using the SAO/NASA Astrophysics Data System (ADS) database. (On ADS, Einstein's h-index was 27, as I reported, and is now 28. On the larger ISI database covering all science, it is 50.) *Time* magazine selected Einstein, Fermi, Hubble, and William Shockley as the most influential 20th-century physicists and astronomers, three out of four in common with the E-index.

The E-index's linear scale allows comparison of magnitudes of impact, something that Lev Landau was interested in.[5] He estimated that physicists of class 1, like Werner Heisenberg, made $10^{-0.5}$ of Einstein's contribution (or an E-index of 316 mE, close to Heisenberg's E-index of 417 mE); class 2, $10^{-1.5}$; class 3, $10^{-2.5}$; and class 4, $10^{-3.5}$. Landau had a class 5, for those making negative contributions—where Ravi Rau clearly thinks those working on citation indices belong!

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Science centers: Ambassadors to the public

I would like to comment on Alan Friedman's article, "The Evolution of the Science Museum" (PHYSICS TODAY, October 2010, page 45). Colombia has several major science and technology centers that feature interactive exhibits. The Maloka Museum in Bogotá opened in 1998 and the Children's Museum, also in Bogotá, was established in 1986. Explora, in Medellín, opened in 2008. Still, most of the population in smaller cities and in rural areas will have, at best, only limited encounters with those institutions.

In our experience with the Fundación Museo de Ciencia y Tecnología in Popayán, Colombia, a local science center having occasional budgets and no endowment, we have been able to engage enthusiastic and receptive audiences across socioeconomic and ethnic groups—if we can reach them. In such an environment, science centers have the opportunity to contribute substantially to public education by developing and disseminating projects, demonstrations, and educational materials for science teachers who often work in isolation and for young people who are anxious for hands-on experience.

Although topical education is important, primary emphasis should be given to the promotion of the scientific worldview—careful observation and reasoned analysis. Science centers ought to be careful not to "stray far from the core content interests" of science and technology and present themselves as centers for entertainment; it is as specific channels to understanding the scientific way of thinking that local science centers uniquely serve the public.

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